ngVLA Science Use Case Analysis and Associated Requirements

Melissa Soriano
Jet Propulsion Laboratory, California Institute of Technology

ngVLA
The Next Generation Very Large Array

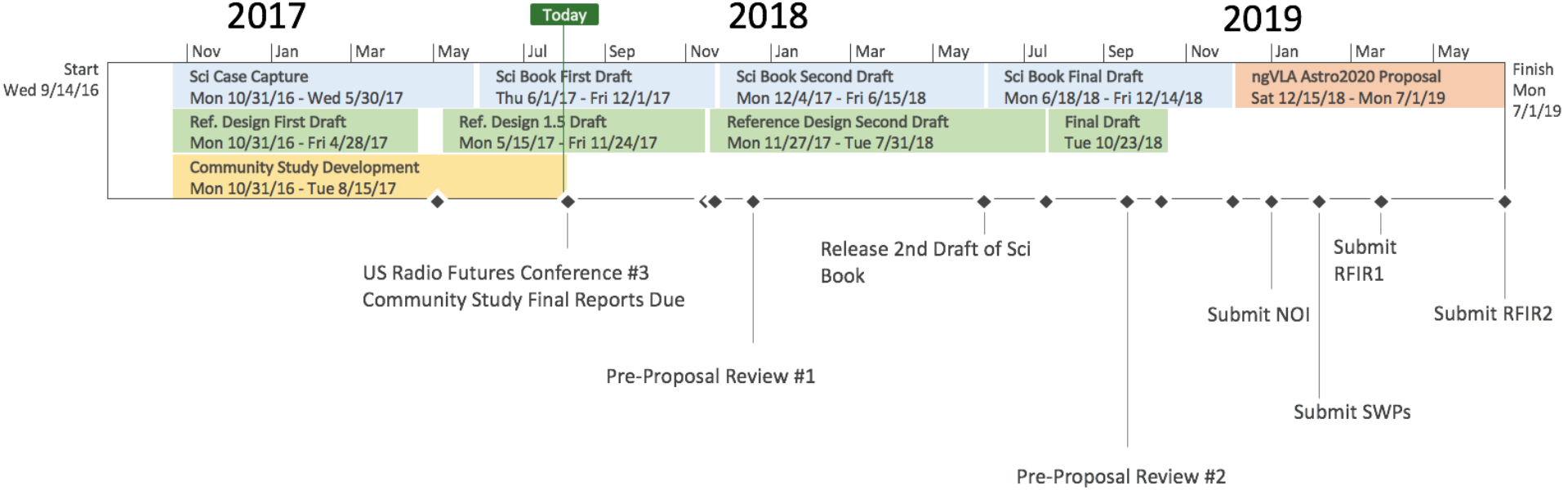
Disclaimers

- The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

ngVLA Proposal Schedule

Goal: NRAO CoDR-level proposal to 2020 Decade Survey

Compelling science program & defensibly costed design of all major elements



Introduction to Technical Advisory Council

- Technical Advisory Council (TAC) formed in February, 2017
- Monthly telecons
- Activities
  - Review of cost model
  - Identification of areas in need of additional study
  - Analysis of key science use cases and associated requirements (this presentation)
  - Review of antenna preliminary specifications document
- Plans
  - Development phase proposal input
  - Review of other key specification documents

TAC members

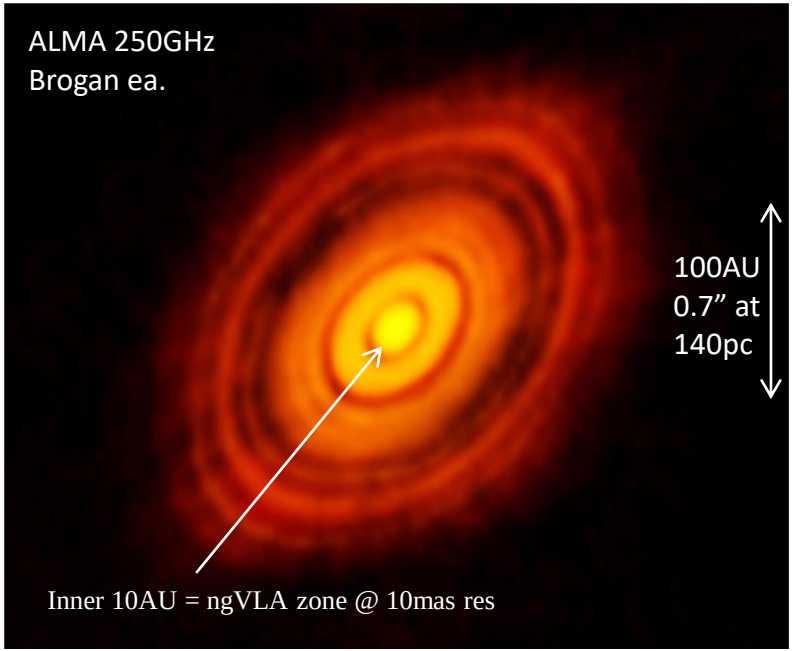
- Sarah Church (Stanford)
- Larry D'Addario (JPL)
- Sean Dougherty (NRC)
- Mark Gurwell (CfA)
- Andy Harris (Maryland)
- Tetsuo Hasegawa (NAOJ)
- Jeff Kantor (LSST)
- Stan Kurtz (UNAM)
- James Lamb (Caltech)
- Michael Rupen (NRC)
- Melissa Soriano (JPL)
- Sandy Weinreb (Caltech)

Key Science Goal #1: Terrestrial-Zone Planet Formation

Current State-of-Art in Planet Formation: ALMA Images of HL tau

The ngVLA will be able to image planetary systems as they are forming.

- Continuum observations, RMS sensitivity is key



Requirements

- 20-40, 90-110 GHz frequency coverage
- < 10 mas angular resolution
- 0.5 μJy/beam RMS sensitivity
- As much instantaneous bandwidth as possible

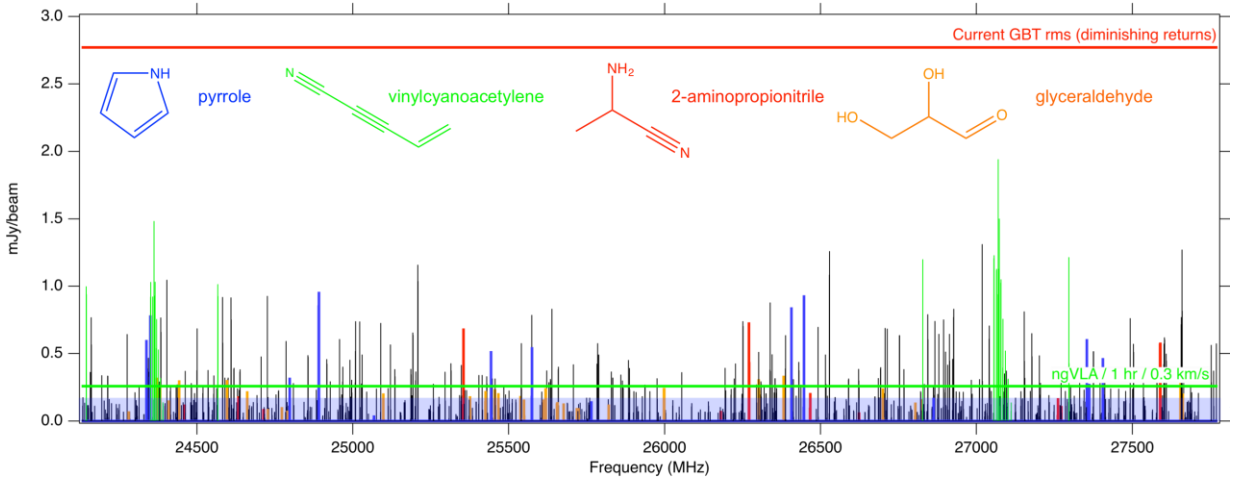
Key Science Goal #2: Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry

The ngVLA will detect complex pre-biotic molecules and investigate the chemical initial conditions in forming solar systems and individual planets

- Spectral line observations, spectral line sensitivity is key

Requirements

- 16-50 GHz frequency coverage
- 50-200 mas angular resolution
- 30 μJy/beam/km/s sensitivity
- 0.1 km/s spectral resolution
- 4 GHz instantaneous bandwidth desirable to observe multiple lines in a single observation



B. McGuire et al

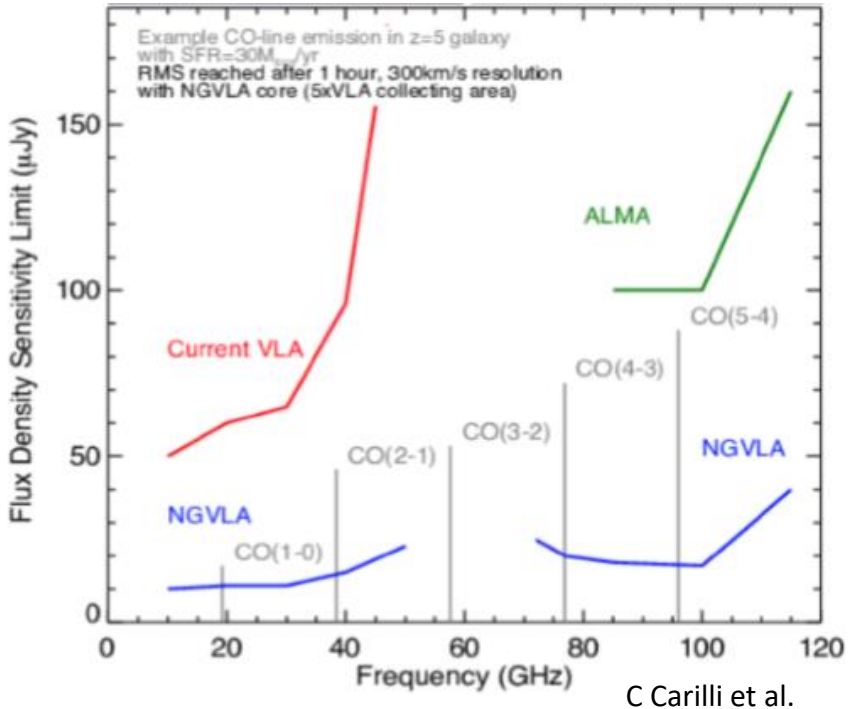
Key Science Goal #3: The Assembly and Structure of Galaxies Throughout Cosmic History

The ngVLA will survey cold CO in highly redshifted galaxies and image the structure of protogalactic disks at any redshift where CO exists.

- Spectral line observations
- Large instantaneous bandwidth is key in probing large cosmic volumes in a single observation

Requirements

- 5-50 GHz frequency coverage
- 100-3000 mas angular resolution
- 10 μJy/beam/km/s sensitivity
- As much instantaneous bandwidth as possible



C Carilli et al.

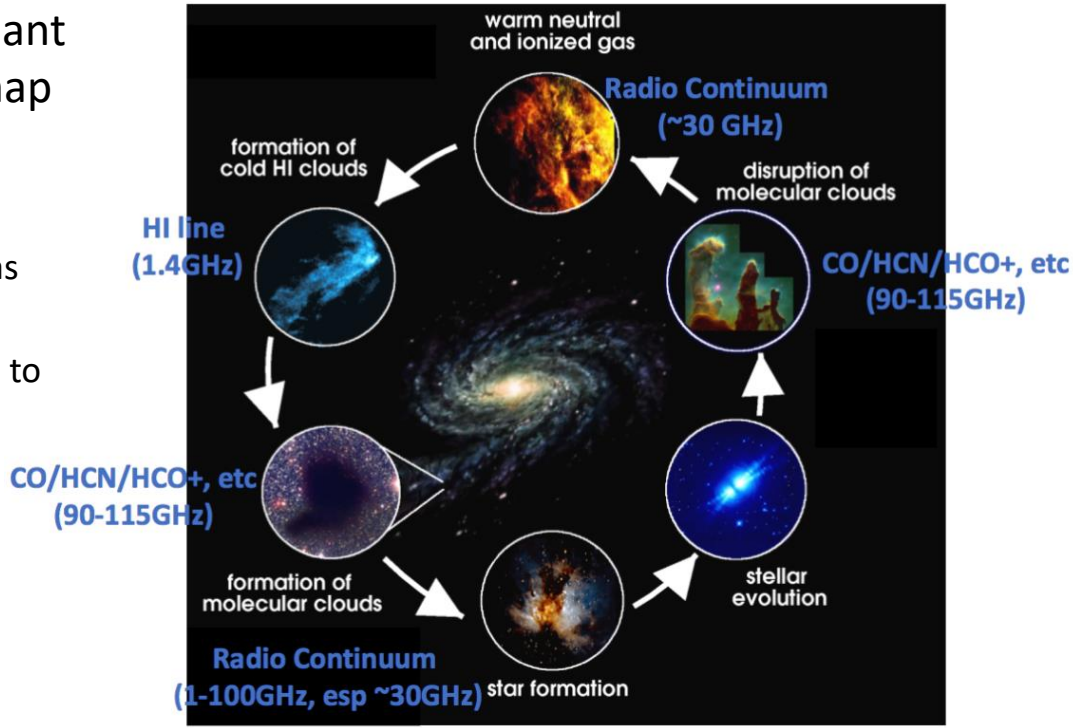
Key Science Goal #4: Understanding How Galaxies Produce New Generations of Stars

The ngVLA can study large samples of giant molecular cloud populations and will map key gas and star formation tracers.

- Spectral line observations
- Broad frequency coverage needed to study HI as well as CO/HCN/HCO+
- Large range of angular resolution requirements to image individual galaxies up to the cosmic web

Requirements

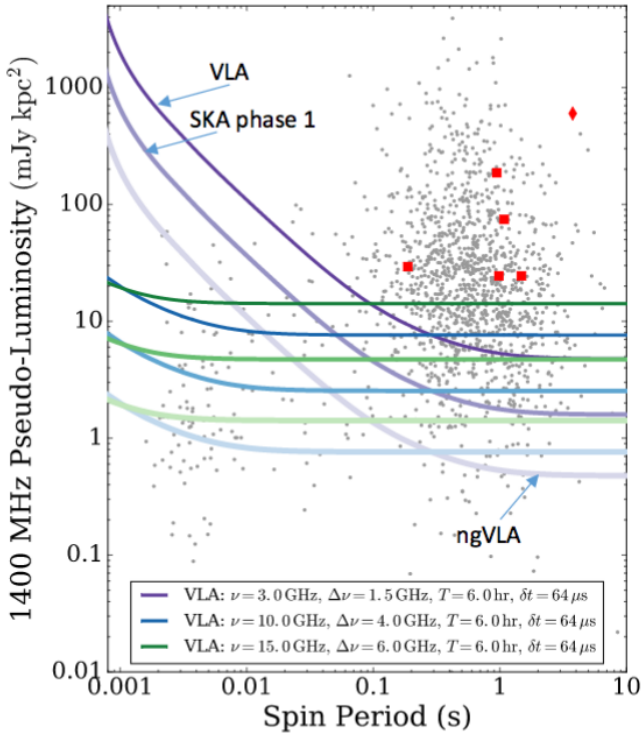
- 1.2-5, 80-120 GHz frequency coverage
- 100-60,000 mas angular resolution
- 8 μJy/beam/km/s sensitivity
- 0.1 km/s spectral resolution
- 4 GHz instantaneous bandwidth



Key Science Goal #5: Pulsars in the Galactic Center as Fundamental Tests of Gravity

The ngVLA will probe into the galactic center area looking for pulsars, which are moving clocks and enable new tests of theories of gravity.

- Continuum observations, RMS sensitivity is key



Requirements

- 2-26 GHz frequency coverage
- 0.05 µJy/beam RMS sensitivity
- 8 GHz instantaneous bandwidth
- Subarrays capability is desirable

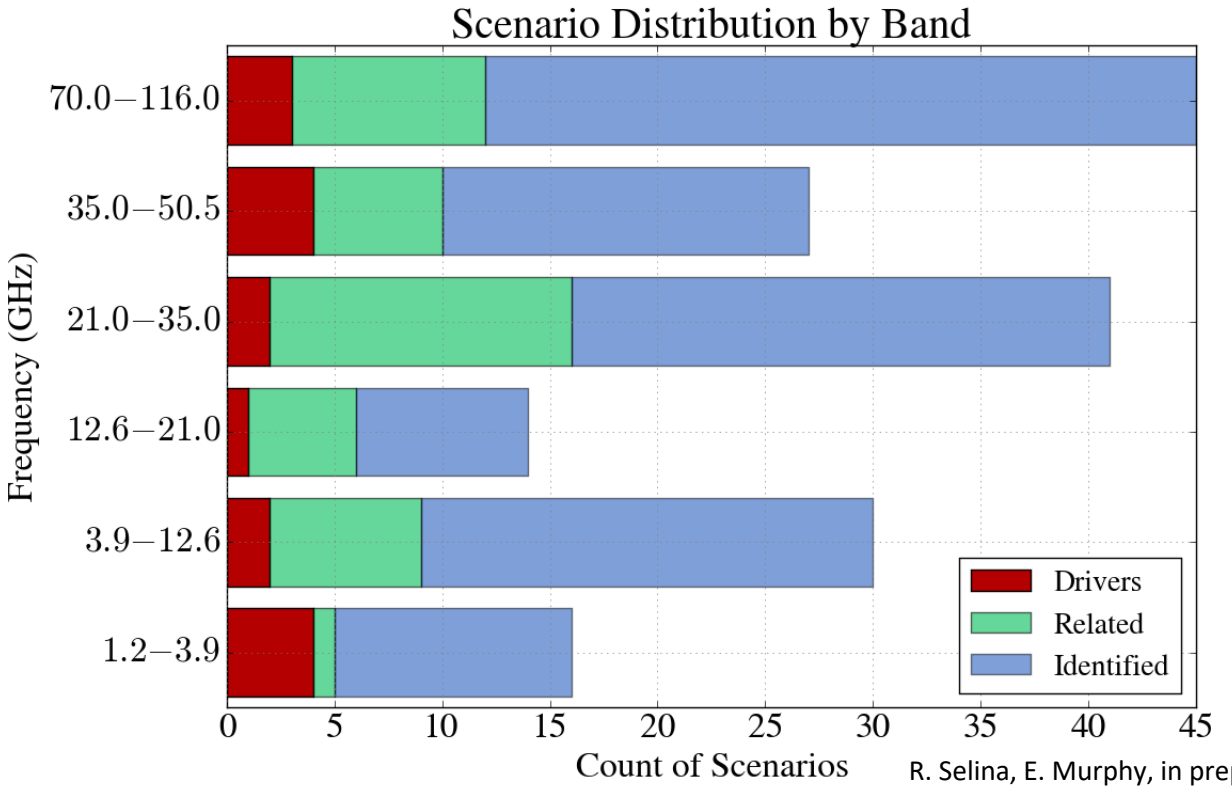
Summary of Requirements Associated with Key Science Cases

Key Science Use Case	Frequency Coverage (GHz)	Angular Resolution (mas)	Sensitivity
1. Terrestrial Zone Planet Formation	20-40, 90-110	<10	0.5 uJy/beam
2. Initial Conditions for Planetary Systems and Life	16-50	50-200	30 uJy/beam/km/s
3. Assembly and Structure of Galaxies	5-50	100-3000	10 uJy/beam/km/s
4. Understanding how Galaxies Produce Stars	1.2-5, 80-120	100-60000	**8 uJy/beam/km/s**
5. Pulsars in the Galactic Center	2-26		**0.05 uJy/beam**

Driving cases for sensitivity requirements

Science Use Cases by Frequency Band

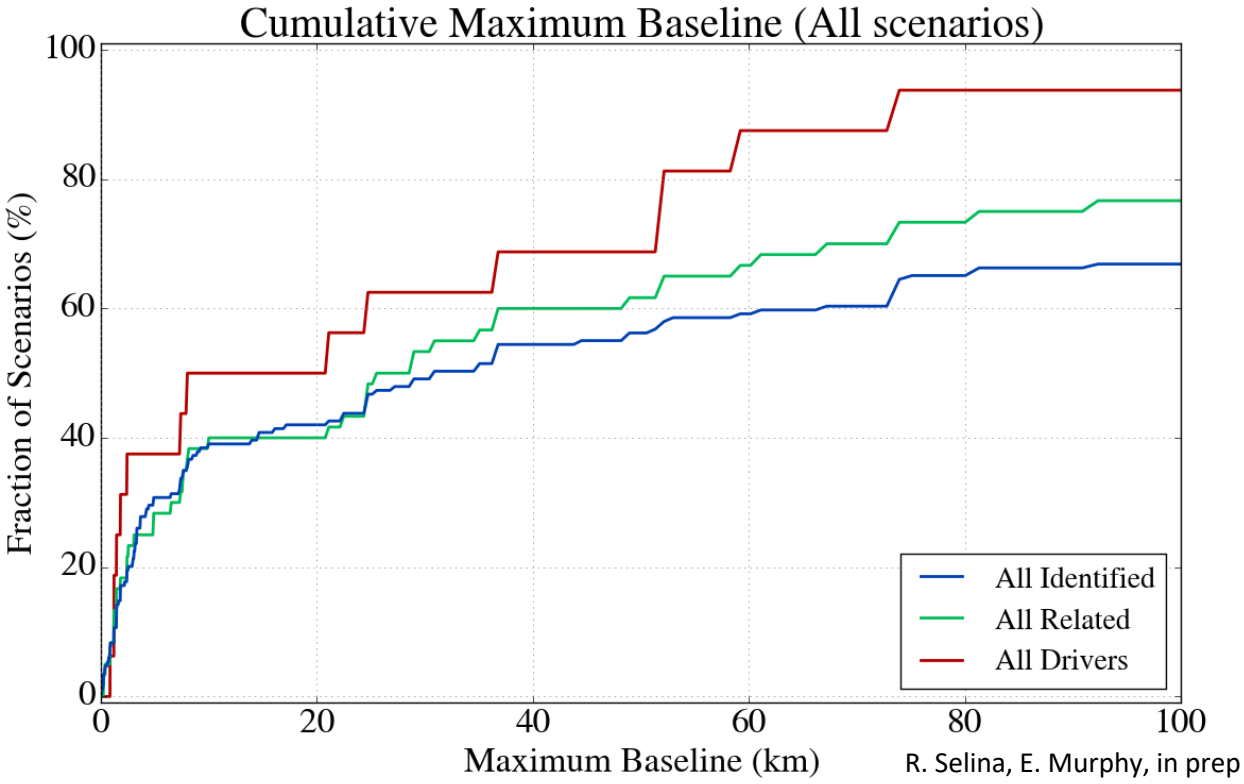
- ngVLA science use cases are distributed over frequencies of 1.2-116 GHz
- ngVLA Working Group survey found that 4-116 GHz frequencies are desirable/essential



R. Selina, E. Murphy, in prep

Science Use Cases by Maximum Baseline

- 90% of ngVLA science use cases require max baselines of 100 km or less
- ngVLA Working Group survey found that 1-30 km baselines are desirable/essential

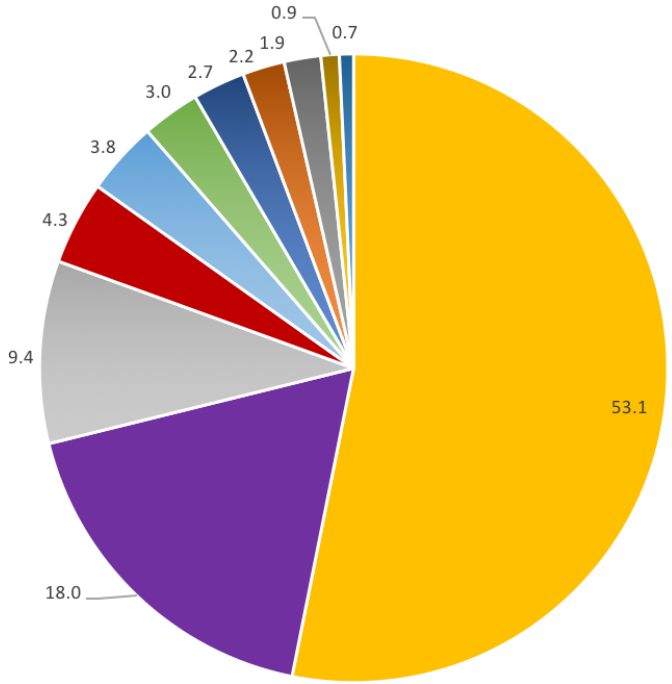


R. Selina, E. Murphy, in prep

ngVLA cost model

- Developed by Rob Selina (ngVLA systems engineer) and Jeff Kern
- 3.07 version of model shown in this talk
- 214 x 18-m offset Gregorian antennas, 6-band receiver configuration, 20 GHz instantaneous bandwidth, 320 km max baseline, 7.65 x effective area of VLA @ 30 GHz
- Cost cap of $1.5B for construction and $75M for operations

ngVLA Construction cost distribution



Percent of cost

- Antennas 53.1
- Antenna Electronics 18.0
- Array Infrastructure 9.4
- Computing & Software 4.3
- Project Management & Administration 3.8
- Buildings 3.0
- Correlator 2.7
- Central/Distribution Electronics (LO, DTS) 2.2
- Commissioning & Scientific Validation (CSV) 1.9
- Systems Engineering 0.9
- IT Infrastructure 0.7

Antenna subsystem is the construction cost driver

ngVLA Antenna Preliminary Technical Specifications

- Draft 0.8 released for TAC review on July 24
- TAC is currently reviewing document, will complete review by August 11
- Includes:
  - Functional and performance requirements
  - Interface requirements
  - Safety requirements
  - Requirements for design- analyses required as part of the design process
  - Plans for verification of requirements

Key Antenna preliminary specifications and comparison with other projects

	Primary Aperture Diameter (meters)	Secondary angle of illumination angle (degrees)	f/D	shaped/ unshaped	surface accuracy (microns) Precision conditions	surface accuracy (microns) Standard conditions	pointing accuracy rms (arcsec) Precision conditions	pointing accuracy rms (arcsec) Standard conditions
MeerKAT	13.5	100	0.55	unshaped	600	600	5	25
DVA-2	15	110	0.8	shaped	335	?	10	180
ALMA	12	7.16	0.4	unshaped	25	25	2	2
SKA	15	110	0.36	shaped	500	500	5	10
ngVLA	18			shaped	160	300	2.7	4.2

Antenna requirements are reasonable when compared to other radio telescope projects in development

Note: Data shown for constructed antennas is requirements, not actual performance. Nighttime/no wind (precision) conditions and daytime (normal) conditions differ for each system.

ngVLA Pathfinder subsystems

- Caltech 4-band ngVLA antenna electronics subsystem developed by Sandy Weinreb and team
- JPL 3-band ngVLA antenna electronics subsystem developed by Jose Velazco and team
- ngVLA pathfinder antenna electronics subsystems could be tested on-sky using DVA-2 (15-m) or OVRO 10.4-m
  - DVA-2 is offset Gregorian design with wide illumination angle like ngVLA. Surface accuracy is 335 microns.
  - OVRO 10.4-m is symmetric Cassegrain design, receiver could be used at prime focus. Surface accuracy is 50 microns.

Thank you